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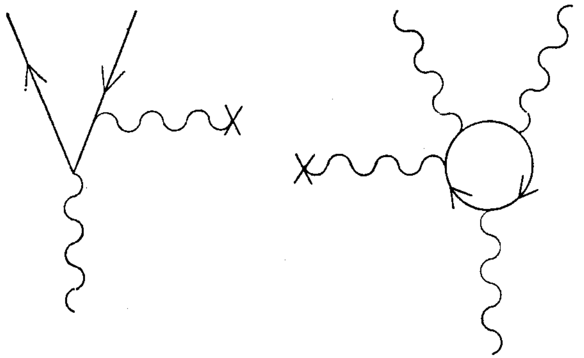
Photons in Magnetic Fields

THE discovery of the rotation of the plane of polarization of light in a magnetic field by Faraday in 1846 led to the interpretation of light as propagating electromagnetic radiation. The Faraday effect has since been the subject of numerous investigations which led to practical applications in plasma diagnostics with microwaves and most recently with lasers. However, it has remained the only effect of magnetic fields on light which received much attention until the advent of modern quantum electrodynamics.

Toll[1] calculated the absorption coefficient of a magnetic field for photons of sufficient energy to produce electron-positron pairs. Similar calculations were carried out also by Klepikov[2] and Roebl[3]. Fig. 1a shows a diagram for this process. The practical observability of the effect was discussed by Erber[4]. Extremely strong magnetic fields (of the order of 10^8 gauss) are necessary to observe the effect in the laboratory, and the achievement of such fields is quite doubtful at this time because of the high magnetic pressures which would be associated with them (of the order of 10^8 times atmospheric pressure).

Fig. 1b shows a diagram for a higher order quantum electrodynamic process in which a pair is produced only virtually, but an additional photon is produced under the influence of the magnetic field. It can be expected that the cross-section for this process is very small; however, there should not be any threshold in photon energy or a high magnetic field requirement as in the process in Fig. 1a. It appears that the matrix element corresponding to Fig. 1b has not been evaluated at this time.

In a mathematical investigation of the propagation laws of characteristic singularities of the equations of gravitation, Stellmacher[5] found that certain of such singularities of the gravitational field equations combined with Maxwell's equations exhibit properties consistent with their interpretation as photons, although no positive identification was made or can be made to-day. Besides such familiar properties as the polarization, Doppler effect, and an invariant resembling an energy, these singularities show a peculiar behaviour under the influence of electric and magnetic fields. The invariant actually has two terms, of gravitational and electromagnetic origin, respectively, which are not separately conserved. A coupling between the two can take place under the



a *b*

Fig. 1. Typical Feynmann diagrams for interactions of photons with electromagnetic fields. *a*, Pair production; *b*, production of secondary photons. The notation follows the usual rules (ref. 9)

influence of electric and magnetic fields which are perpendicular to the direction of motion. (It is shown, however, that the oscillatory electric and magnetic fields associated with the singularity itself have no such effect.) If one assumes that all the energy is initially in the electromagnetic term, then it is being transferred to the gravitational term according to:

$$\frac{\Delta(h\nu)}{h\nu} = \alpha\int[(E_x - B_y)^2 + (E_y + B_x)^2]^{1/2}\,dz, \qquad (1)$$

where E and B denote electric and magnetic fields, respectively, and the spin and motion are in the x and z directions, respectively. The coupling constant is:

$$\alpha = \sqrt{2\gamma}\,c \approx 4 \times 10^{-24}\ \text{cm}^{1/2}/\text{g}^{1/2}, \qquad (2)$$

if the fields are in electromagnetic C.G.S. units, and where γ is the gravitational constant and c the velocity of light.

Let us assume that the identification between the singularities and photons can be made. Then the effect would mean an (apparent) energy loss of the photons in transverse electromagnetic fields which should show up as a red shift. It is easy to see that this shift is extremely small and negligible in most cases. The quantum electrodynamic process according to Fig. 1*b* is likely to act in the same direction, that is, one of the photons is probably much less energetic than the other; however, it is difficult to predict the relative magnitudes of the two effects.

An experimental investigation may soon become possible. The Mössbauer effect permits in principle the measurement of a frequency shift of one part in 10^{15}, and there is hope that the laser technology will permit the measurement of shifts of the order of one part in 10^{14} over very short times[6]. In a field of 10^6 gauss one would need paths of 2·5 and 25 m in the two cases, respectively, where the laser path of 25 m may be more easily realizable, because mirrors can be used. It is also quite possible that the quantum electrodynamic effect will turn out considerably larger than indicated for the singularities in equation (1).

The recognition that magnetic fields exist throughout our Galaxy and quite possibly in intergalactic space suggests the intriguing possibility that part of the observed red shift of spectral lines emitted by distant stars and galaxies may be due to the interaction of the photons with electromagnetic fields in space. A transverse magnetic field of the order of several gammas throughout space will, for example, result in the observed shift[7] if equation (1) is valid. Present estimates suggest a magnetic field of the order of one gamma in our galactic system[8].

It should be of modest interest to have an evaluation of the matrix element corresponding to Fig. 1*b* and possibly an experimental investigation of the magnetic redshift.

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G. K. OERTEL

Magneto-hydro Dynamics Section,
National Aeronautics and
Space Administration,
Langley Research Center,
Langley Station,
Hampton, Va.

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